Approaches for Efficient Coupling of Lasers to Telescopes with Secondary Mirror and Baffle Obscuration

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ABSTRACT

For free-space propagation, often laser sources with Gaussian intensity profile are utilized. A Cassegrainian telescope's central obstruction can block a significant amount of the transmitted beam energy. The previously known approaches to solve the problem include: use of an axicon optical element and or sub-aperture illumination of the telescope primary mirror. Two new approaches have been identified to eliminate all secondary mirror and baffle vignetting. These approaches include a beam-slicer and a beam-splitter/combiner optics. The new approaches eliminate the precise alignment required for axicon devices and are simple to fabricate. The beam-splitter/prism combiner approach results in a clean far field pattern and has transmission divergence that is limited to the diffraction limit for each of the sub-aperture transmission beams.
Keywords: beam coupling, axicon, beam slicer, sub-aperture, and optical communications

INTRODUCTION

Use of a laser with TEM_{00} spatial output beam quality is typically preferred for both laser-communications and lidar applications. These applications commonly utilize reflecting telescopes with on-axis secondary mirrors that obscure the primary mirror [1,2]. When a laser with TEM_{00} output beam, characterized by a strong peak in the middle of the Gaussian distribution, is coupled to an obscured telescope, the most useful part of the beam is clipped resulting in 50% or more loss of the optical telescope antenna gain. Assuming that the secondary mirror and baffles block a modest 8.4% of the beam area, the telescope secondary obstruction actually blocks approximately 30% of the beam energy. Some Cassegrainian telescopes can have mirror and baffle obstructions that are half the diameter of the primary mirror. While this size obstruction only blocks 25% of the beam area, it actually blocks 65% of the energy in a Gaussian beam. Only 35% of the beam energy is transmitted through the Cassegrainian telescope. Four approaches (two new and two known) have been analyzed for efficient coupling of lasers. Although, these schemes all increase the number of optical surfaces in the overall optical path, with proper optical coating, only minor losses are encountered at each additional optical surface. The overall gain in transmitted power can be as much as 50% or more depending on how much of the beam would have been vignetted by the telescope secondary mirror and baffle. The following assumptions were made in the analysis: aperture diameter =100 mm; wavelength = 1064 nm; divergence = 34 μrad; transmit source = fiber-coupled laser diode; Fiber's NA= 0.1; fiber core diameter = 10 μm; central obstruction diameter = 29 mm.

Approach # 1: Axicon Optical Element

Use of axicons for efficient coupling to telescopes has been analytically and experimentally evaluated before [3,4]. The axicon is a conical with both transmitting and reflecting optical surfaces. A hollow beam is generated upon total reflection of a Gaussian beam from the axicon. Due to difficulties in fabricating the precise conical device, axicons have found limited usefulness. Axicons place restrictions on the field-of-view of the system.

Figure 1 schematically illustrates a Cassegrainian telescope transmitter system equipped with an axicon device to eliminate the secondary mirror and baffle vignetting. Losses due to Fresnel reflection and absorption at the transmitting and reflecting surfaces can be kept small by the proper choice of coatings.

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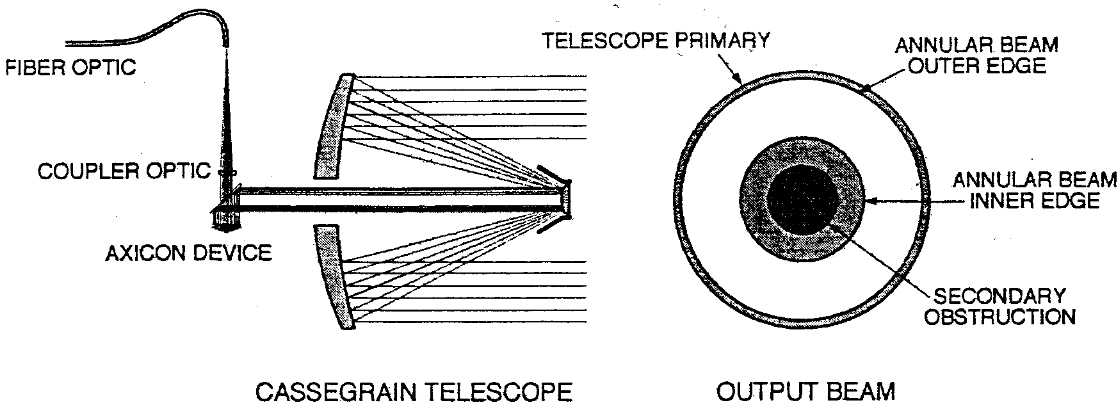


Figure 1. Axicon device implemented with a Cassegrainian telescope

Since the axicon turns the beam inside out, it causes a change in the intensity distribution across the exit beam and thus the far-field pattern. The intensity distribution of the exiting beam will be altered such that the intensity will fall off both towards the inside and outer edges of the exiting annular beam. The exiting beam intensity profile will produce a far-field pattern that is quite Gaussian in appearance. Diffraction rings will generally be suppressed and may not be noticeable. Figure 2 shows the far field pattern for a uniformly illuminated beam with and without the effects of the axicon device.

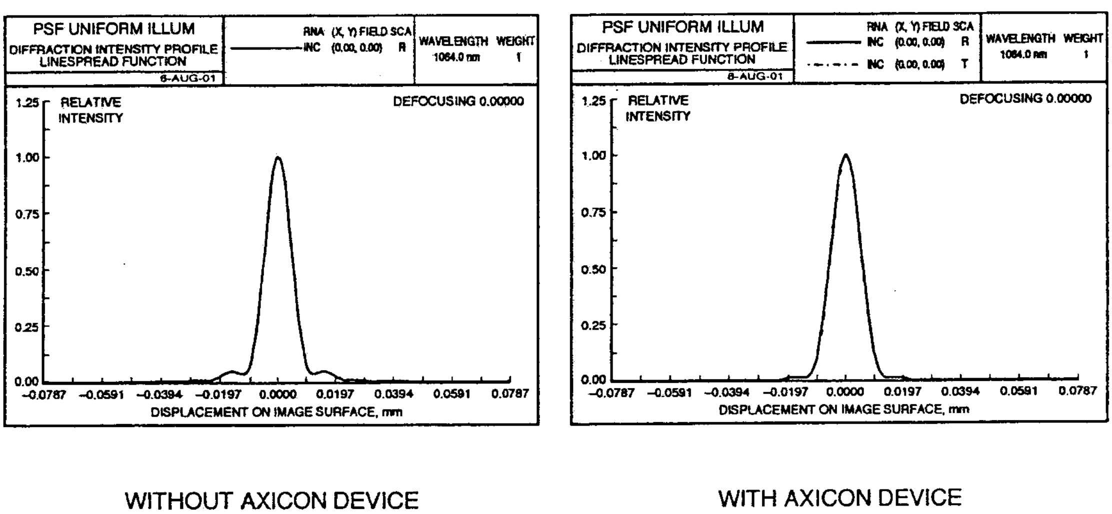


Figure 2. Far-field pattern produced by the axicon input and output beams

Approach #2: Sub-Aperture Illumination

This is the simplest arrangement that can be implemented to avoid the secondary mirror obstruction. In the sub-aperture illumination approach, the transmit beam is coupled to the telescope so that it is offset at a sub-aperture of the telescope aperture. The secondary mirror and baffle are avoided by this method. The arrangement is shown in Figure 3. The drawback is that beam divergence would be higher than if the entire aperture were to be used.

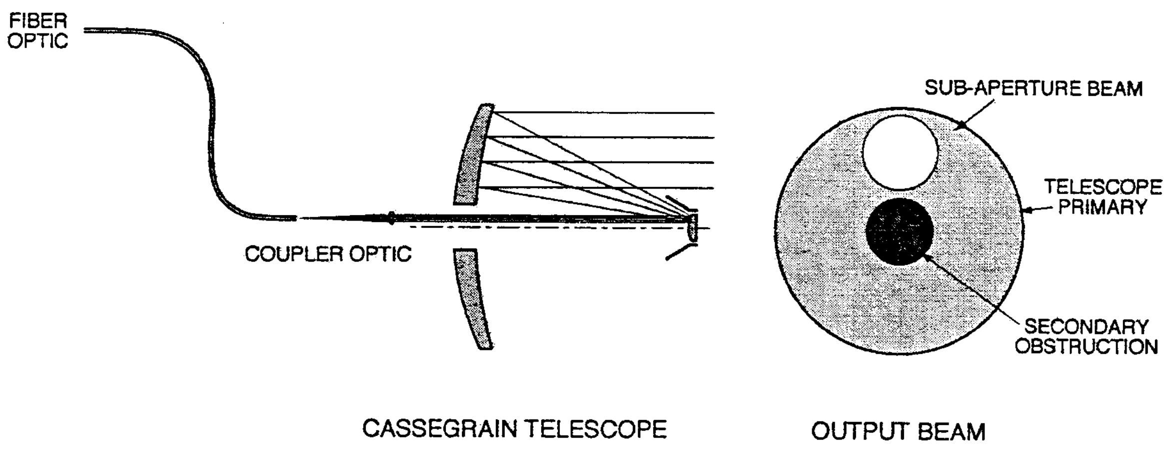


Figure 3. Sub-aperture approach layout

The far-field pattern for this approach is the same as the source. The telescope optical system does not significantly change the far-field pattern. The far-field pattern for the sub-aperture approach is shown in Figure 4.

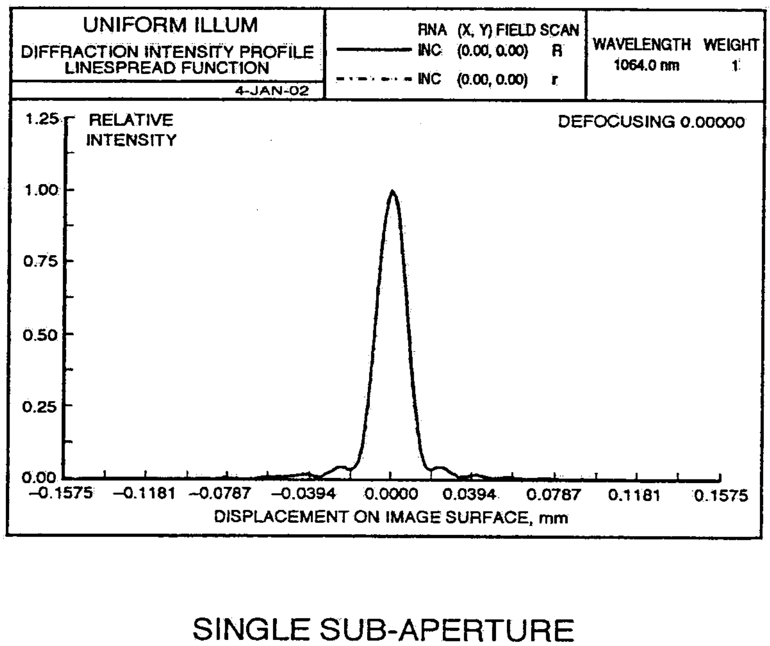


Figure 4. Far- field pattern for the single sub-aperture approach

Approach # 3: Prism Beam Slicer

This is a new approach for laser beam coupling to obscured telescope loss avoidance. A prism device that operates much like the axicon may be used to avoid the Cassegrainian secondary mirror and baffle vignetting. Unlike the axicon device, the prism slicer does not have any curved optical surfaces. However, like the axicon device, the prism slicer is both an afocal refractive and reflective optical element. As with the axicon, it utilizes both transmitting and reflecting optical surfaces. In cross-section, the prism slicer looks exactly like the axicon device. The cross-section geometry is identical. The prism device essentially slices the beam emitted from the transmit laser coupling optic into two or more pie-shaped beams that are then arranged in a circular pattern around the telescope aperture. Each beam is sub-aperture in size and can pass through the Cassegrainian telescope without any additional vignetting from the telescope secondary mirror and baffle. The optical arrangement for a prism slicer that produces four beams is shown in Fig. 5.

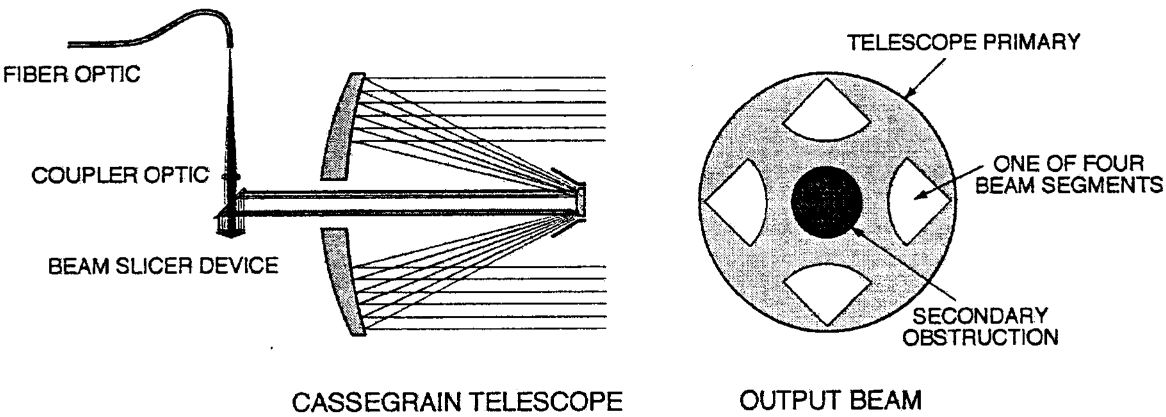


Figure 5. Beam slicer device implemented with a Cassegrainian telescope

The difference between the axicon and the prism slicer is the use of multiple flat surfaces for the rear side of the slicer. Instead of a conical rear surface, the prism slicer utilizes several flat surfaces in the form of a pyramid. These flat surfaces have the same angle as the conical surface in the axicon device. As many even numbered facets as desired may be utilized. Implementing an infinite number of facets would result in an optical element exactly like the axicon. Figure 6 shows a detailed layout of the prism slicer device with four facets.

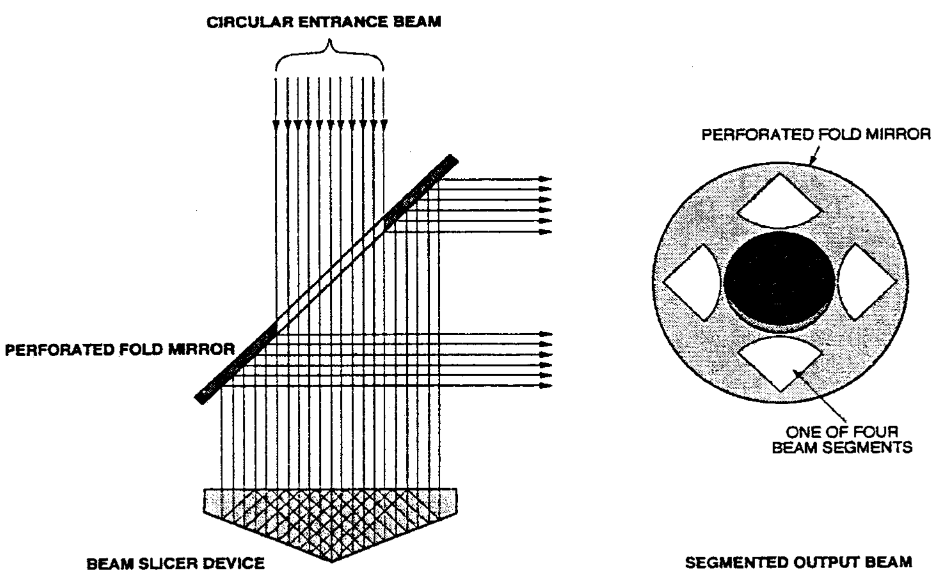
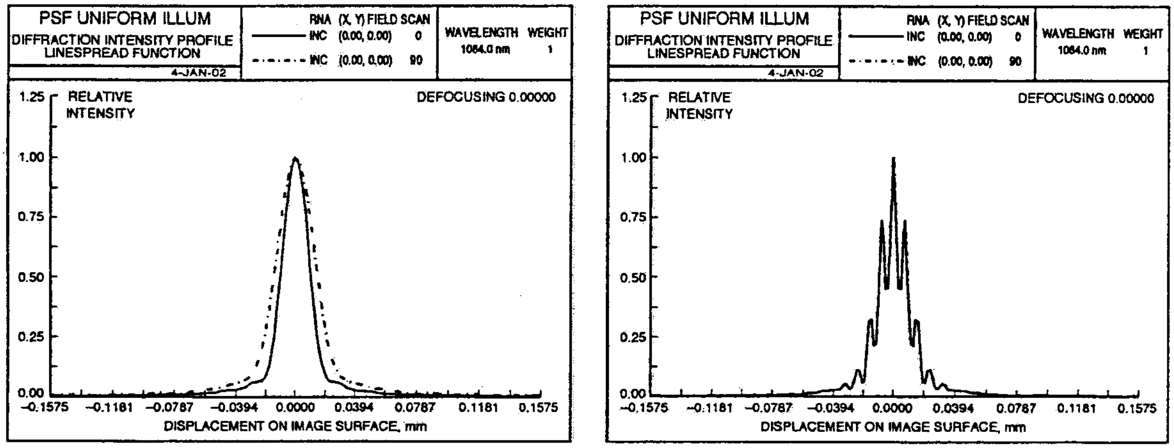


Figure 6. Prism beam slicer device layout

Because with the prism slicer each beam is pie shaped, the far-field pattern unlike that produced by the axicon system is not symmetrical. However, as shown in Figure 7, the combined far-field pattern for the four beams will be nearly symmetrical.



SINGLE BEAM

FOUR BEAMS IN PHASE

Figure 7. Far field pattern for a single prism slicer beam and for four prism slicer beams that are phased

Approach # 4: Beam-Splitters / Beam Combiner

This new approach involves a number of beam-splitters and mirrors as exemplified in Figure 8.

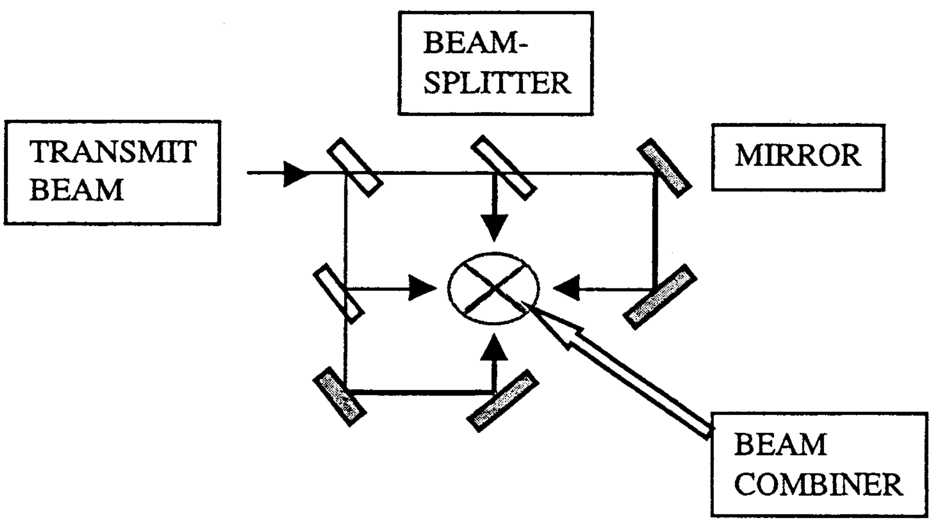


Figure 8. Schematic of the beam-splitter / prism beam combiner configuration

This approach is a variation of the sub-aperture approach where instead of a single beam; this approach produces multiple beams equally spaced in a circle at the telescope aperture. An application of this approach is beam combining. The combiner prism/mirror approach allows multiple fiber-coupled laser diode sources to be combined in a way that does not result in any vignetting by the Cassegrainian telescope secondary mirror and baffle.

In this approach, the collimated output of four fiber-coupled laser sources is directed towards a 45° inclined pyramid-shaped mirror from four different directions 90° apart. The four beams are then directed towards a combiner mirror and the telescope secondary mirror of the telescope. The arrangement is shown in Figure 9. Depending on the orientation of the prism/mirror element, the fold mirror may not be required.

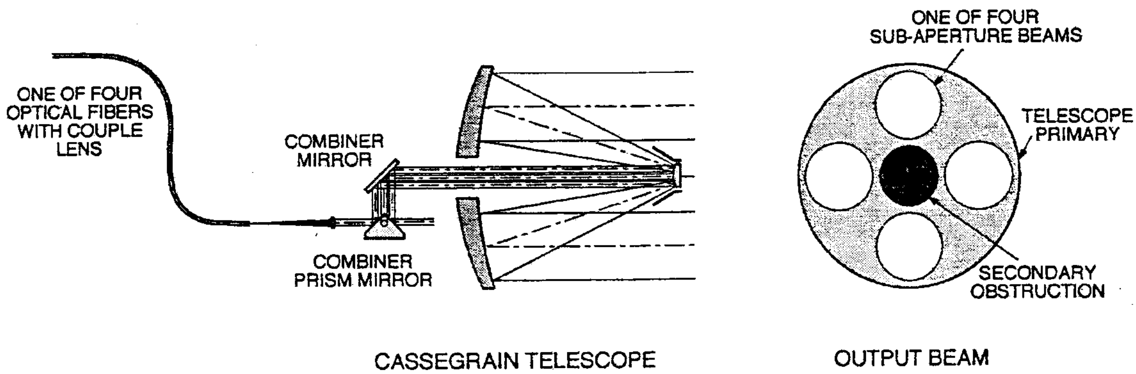


Figure 9. Beam-splitter approach layout

A shown in Figure 10, the far-field pattern for each beam will be the same as the source. If the laser beams are emanated from different sources, the beam pattern of the four beams combined in the far field will be the same as one of the sources.

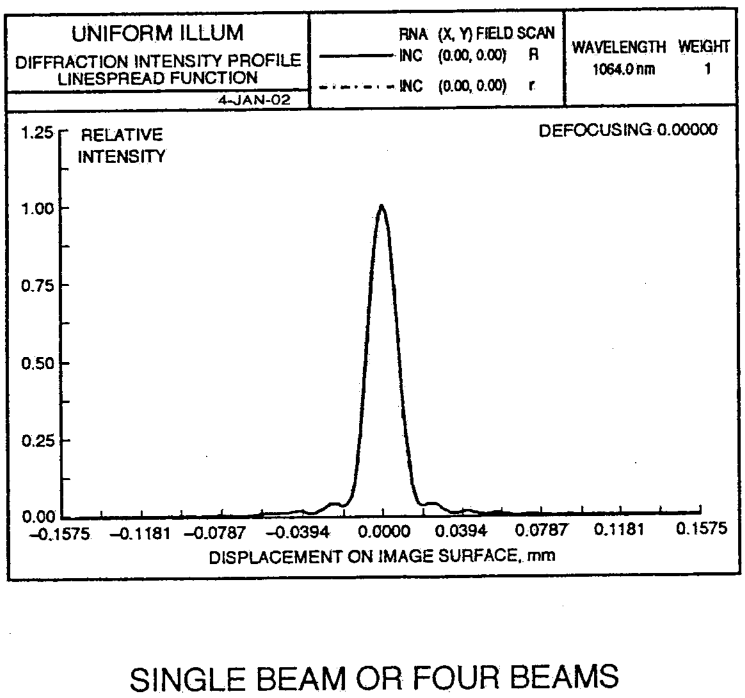


Figure 10. Far field pattern for the four sub-aperture beams

SUMMARY

The merits of the four different schemes, that result in about 50% improvement of efficiency coupling lasers to obstructed telescopes, are summarized and compared in Table 1.

Characteristics	Approach			
	Axicon (Conical)	**Prism Beam Slicer**	**Sub-Aperture**	**Beam-Splitter**
Fabrication complexity	High	Low	N/A	Medium
Alignment sensitivity	High	Low	Low	Low
Far-field pattern performance degradation	Low	Medium/Low	Low	Low
Effective transmittance	High	High	Highest	Medium/ High
Approach/Device field-of-view (FOV) limitation	Very small angles only	Telescope FOV	Telescope FOV	Telescope FOV
Overall improvement in antenna gain	High	High	High	Medium/ High

Table 1. A comparison of merits of the four different schemes showing advantages and disadvantages for each. FOV stand for Field-Of-View

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